Landing and Perching on Vertical Surfaces with Microspines for Small UAVs

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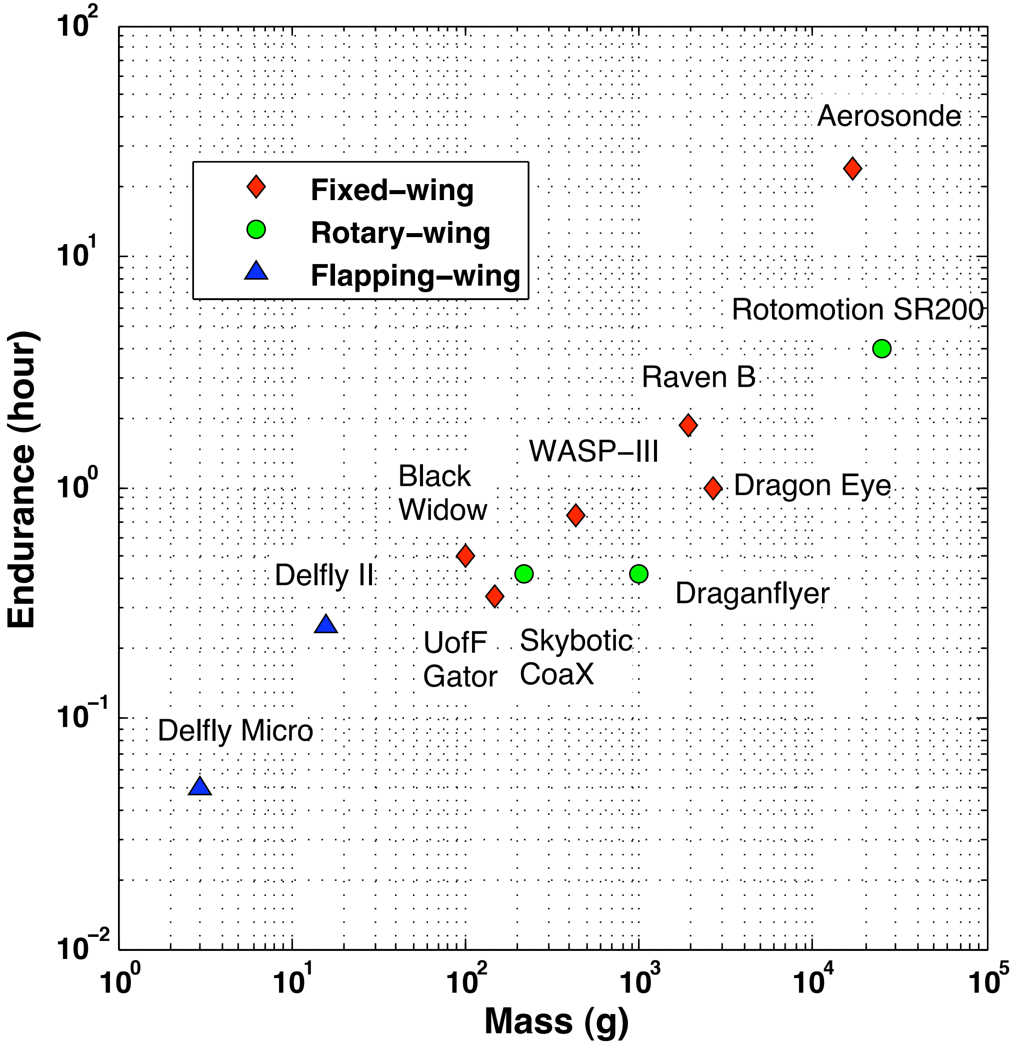
UAV'09, Reno


BBC Motion Gallery
5583-3

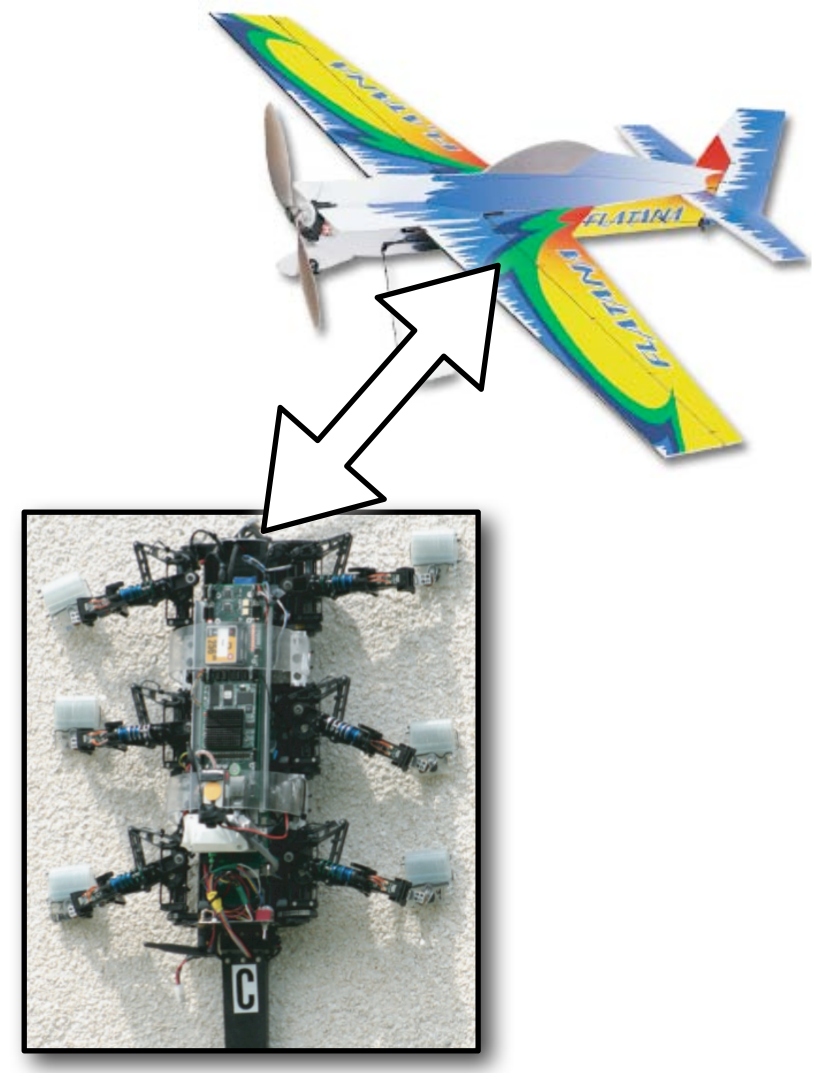
Why should we perch?

- Small airplanes have limited endurance
- Other techniques can only provide limited benefit:
  - Energy extraction from gusts [Patel & Kroo 2006]
  - Optimization [Grasmeyer 2001]
- Perching would increase mission duration to **extended period of time (i.e. days or weeks)**



Other Advantages of Perching

- Stable vantage point while perched vs fast dynamics of small UAVs during flight
- Possibility of landing and physically interacting with the landing surface.
- Perching combines the best of climbing and flying:
  - Agile and fast while flying
  - Can cover long distances
  - Limited energy consumption while perched
  - Wait for better weather conditions
  - Quiet (no motor noise)

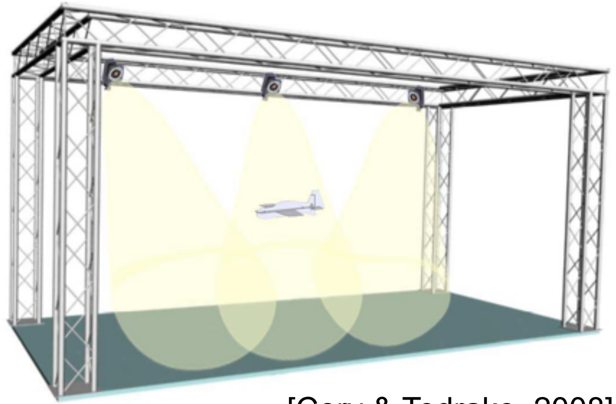


Why Vertical Surfaces?

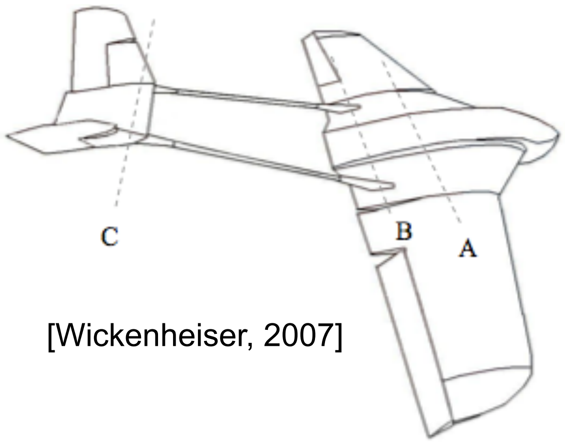
- Walls are common in urban environment
- Walls are easy to detect (at least easier than a passive wire or pole)
- Walls provide a large surface to perch on
- Walls remain relatively free of debris.

Related Work

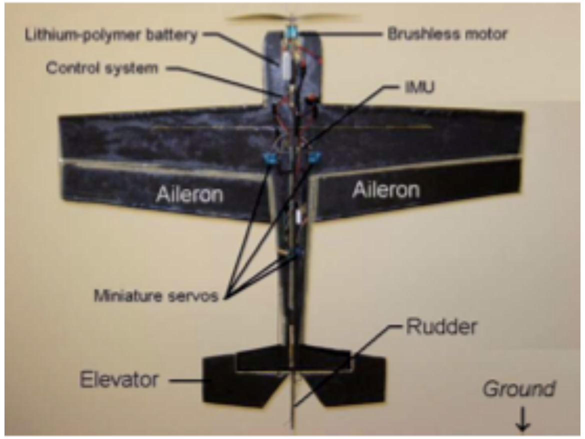
- On agile flight:
  - J. How et al. (MIT) on indoor flying and hovering
  - P. Oh et al. (Drexel) on autonomous hovering
- On perching aerodynamics & control:
  - Wickenheiser et al. (Cornell) on vehicle morphing for perching
  - Tedrake et al. (MIT) on controllability of fixed-wing plane for perching on a wire
- **No explicit consideration of the landing system**
- **Slow maneuvers sensitive to disturbances**
- **Use of highly accurate motion capture system/sensors to enable control**



[Cory & Tedrake, 2008]



[Wickenheiser, 2007]



[Green & Oh, 2006]

Research Goals

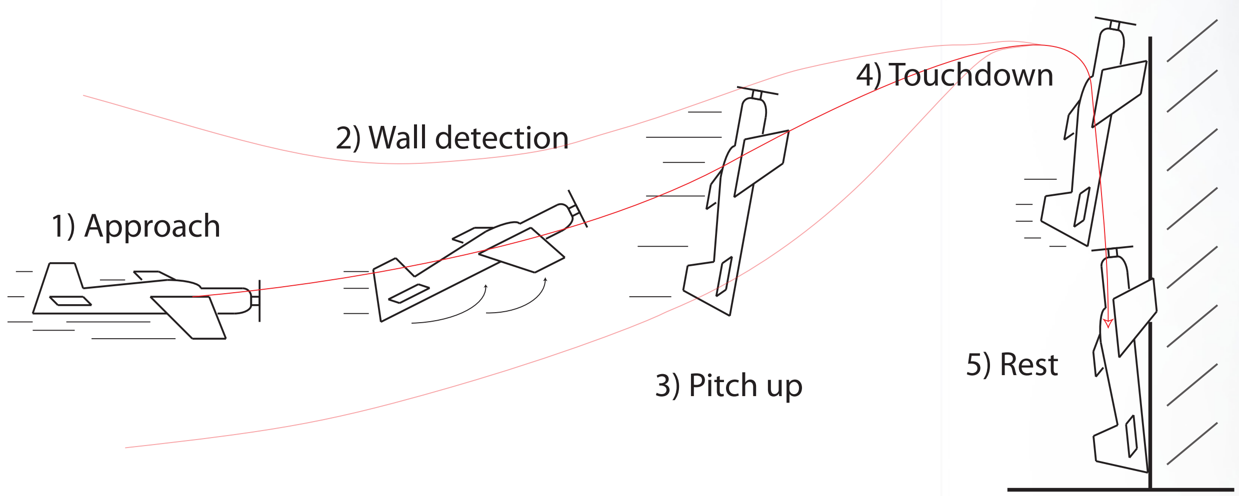
Allow a small airplane to **perch autonomously** on a variety of vertical surfaces

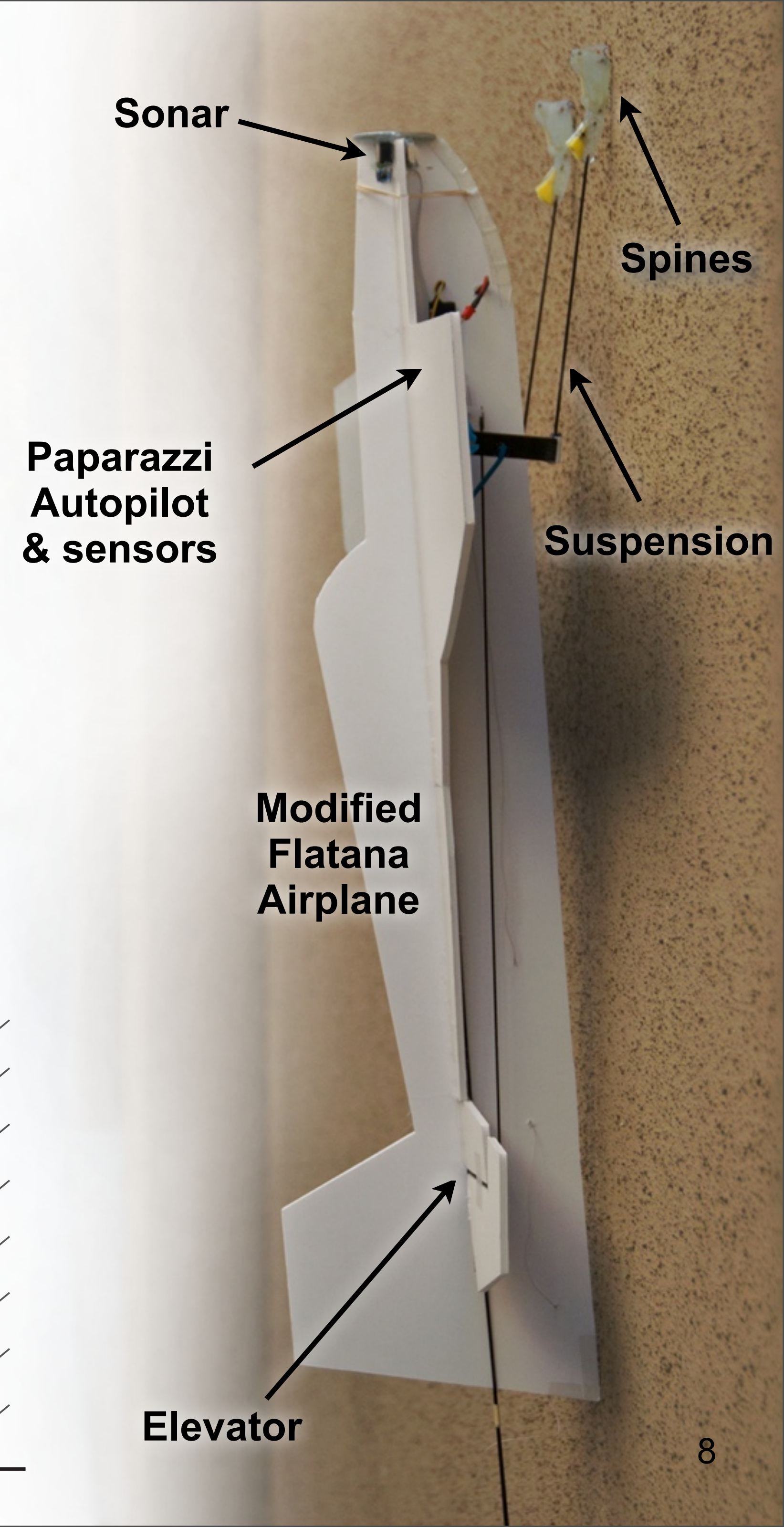
Keep the system simple and lightweight

Maintain the efficiency of conventional airplanes

Our Approach

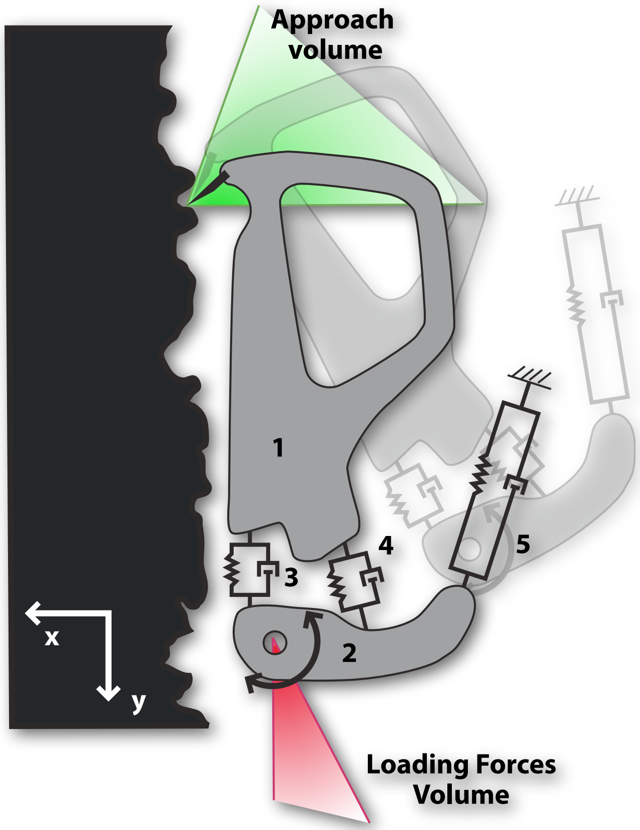
- Quick maneuver to minimize disturbance effects
- **Focus on the suspension and spines** to simplify sensing and control
- **Everything onboard!**





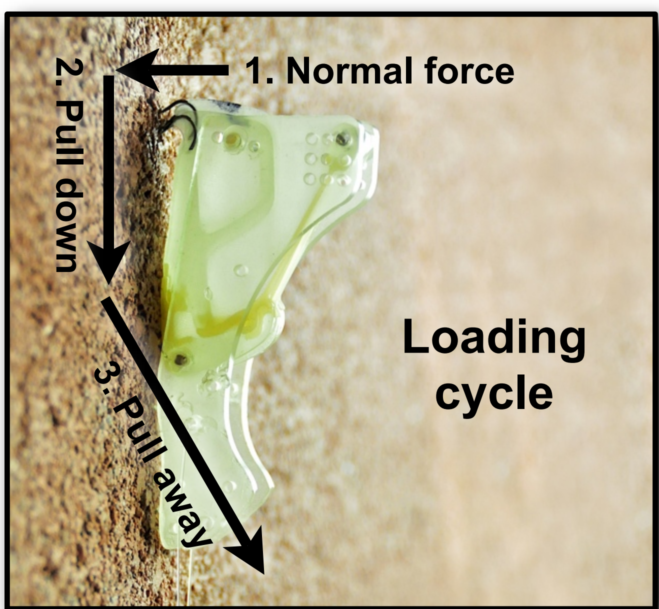
Sticking to the wall

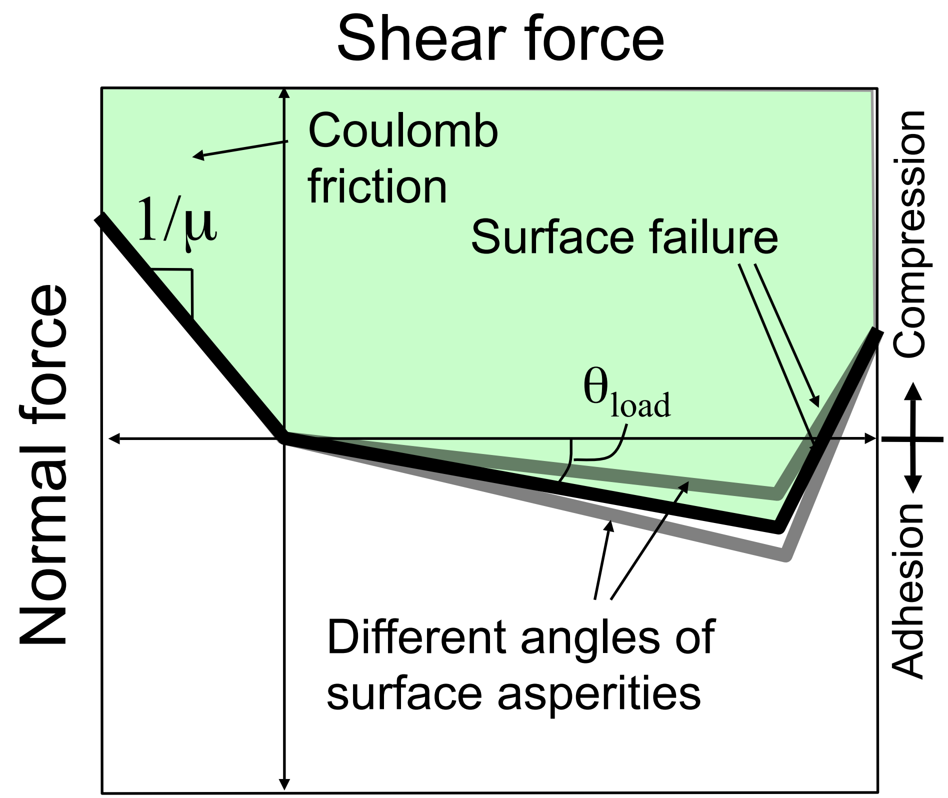
- Small spines (10-15 μm tip radius) that catch and hang on asperities
- Individual spine suspensions distribute the load
- Why spines?
  - They require no power
  - They work on a wide range of outdoor surfaces
  - They are relatively unaffected by films of dirt and moisture
  - They leave no trace of their passage
  - They provide directional adhesion (multiple loading cycles)



Spine Limit Surface

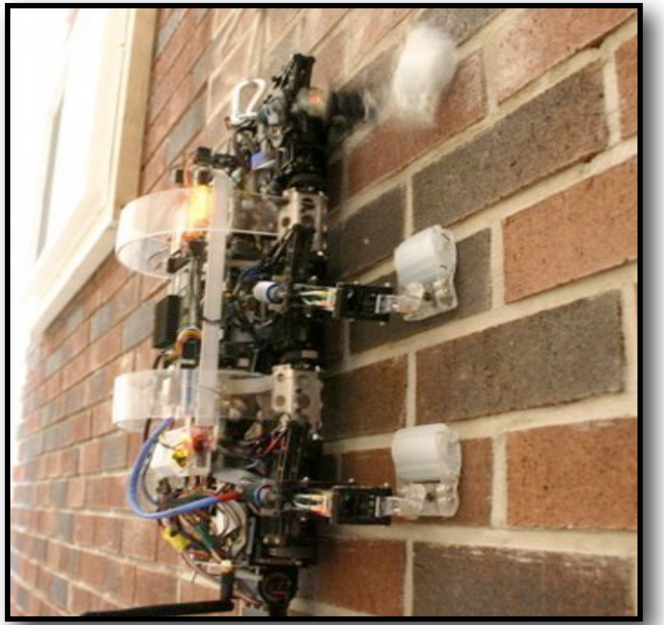
- Spines require a particular loading cycle to engage asperities on the surface without slipping or failing

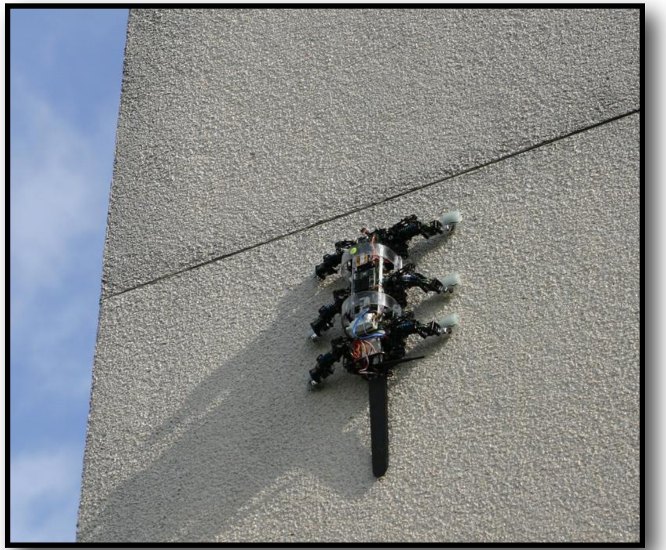




Spine Performances

- Used on Spinybot and RISE to climb brick, stucco, concrete and rock
- Climbing robot spine suspensions take advantage of the robot's control over foot trajectories and forces
- With UAVs, the challenge is to provide desired forces and velocities at the instant of contact with the wall



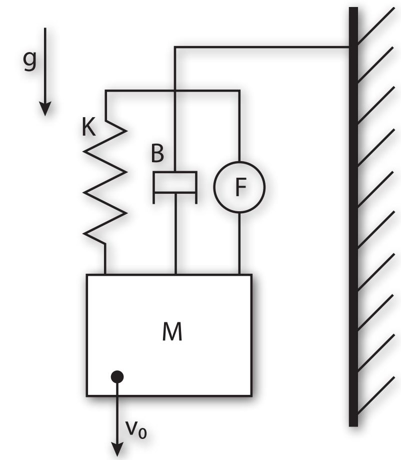


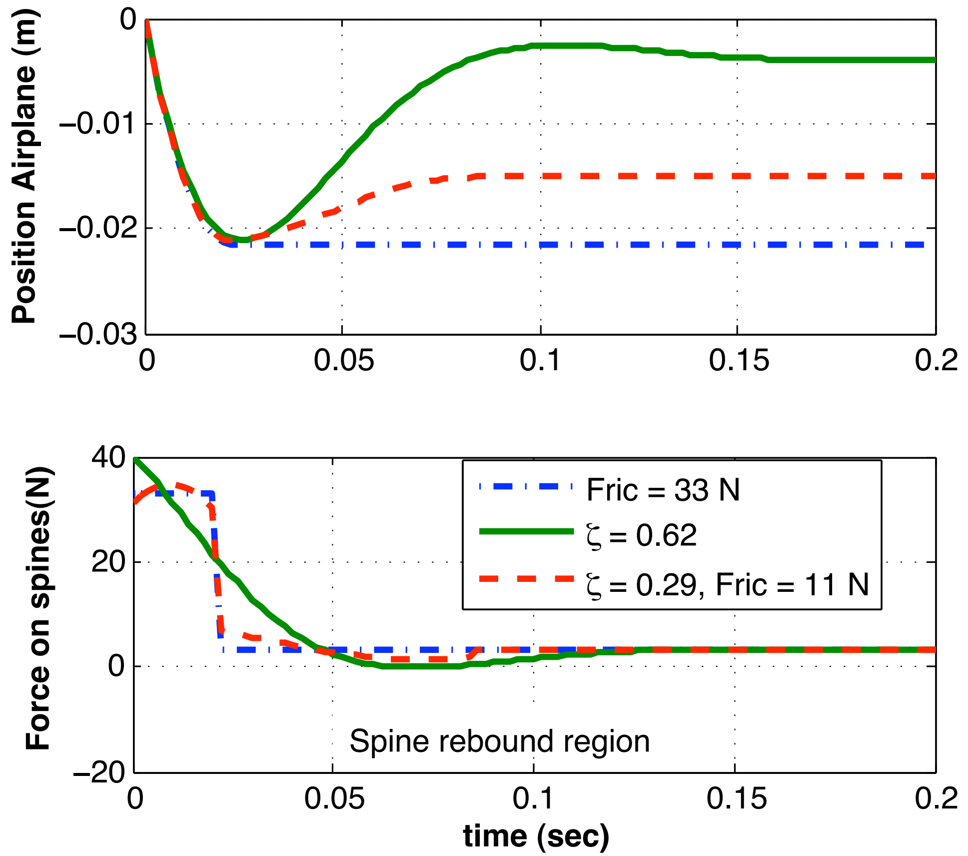
Suspension

- Tests reveal that **vertical rebound** was the main failure mode
- Goal is to find the optimal components (spring, damper, nonlinear elements) to:
  - Minimize peak landing force
  - Minimize suspension travel
  - Prevent negative force, to stay on the wall (vertical rebound)
- Maximum energy dissipation achieved with constant force during the impact

Simple Model

- Vertical model of a spring, damper and coulomb friction suspension
- Damper creates forces dependent on initial velocity
- Coulomb friction provides constant force
- Balance friction and damper to get desired properties



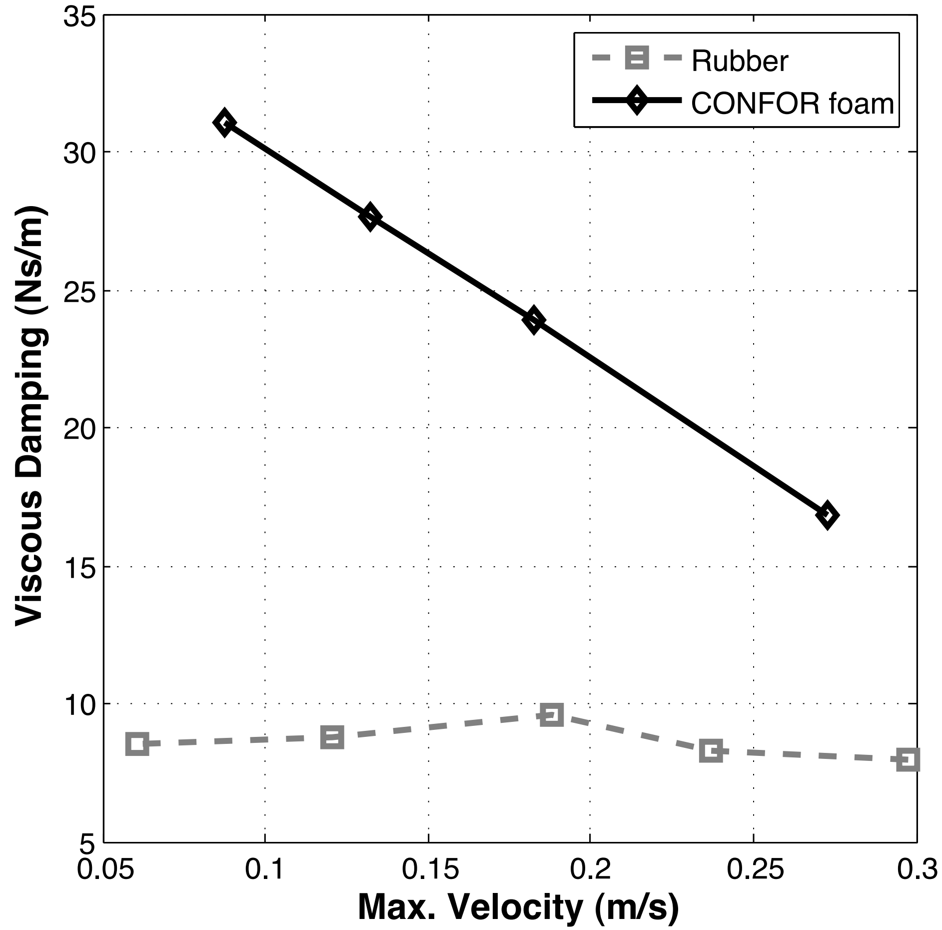


Non-linear properties

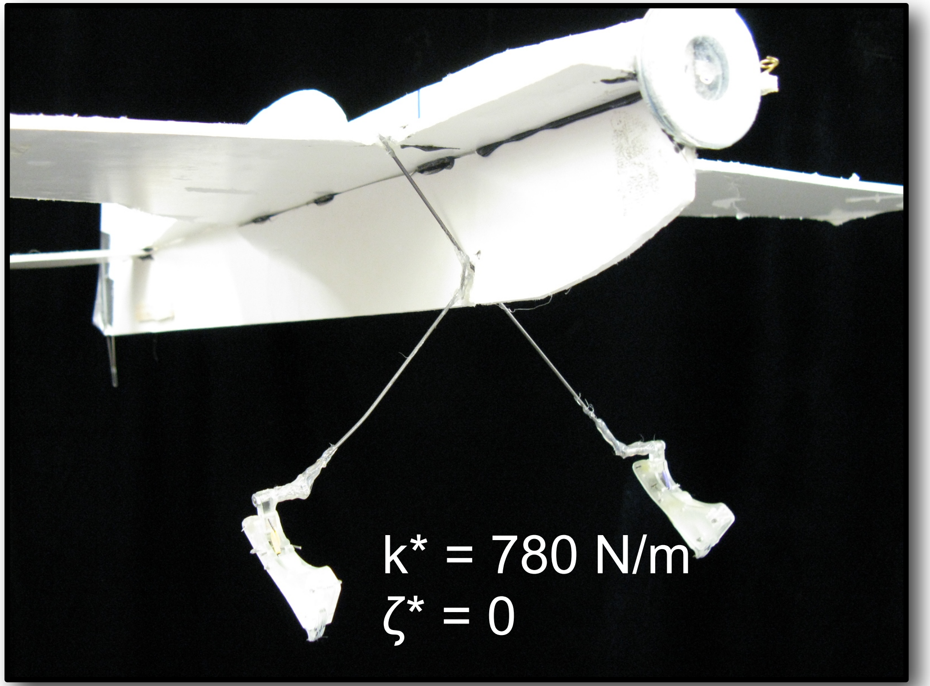
- Material properties can be used to create constant force
- Damping scaled w.r.t position and velocity:

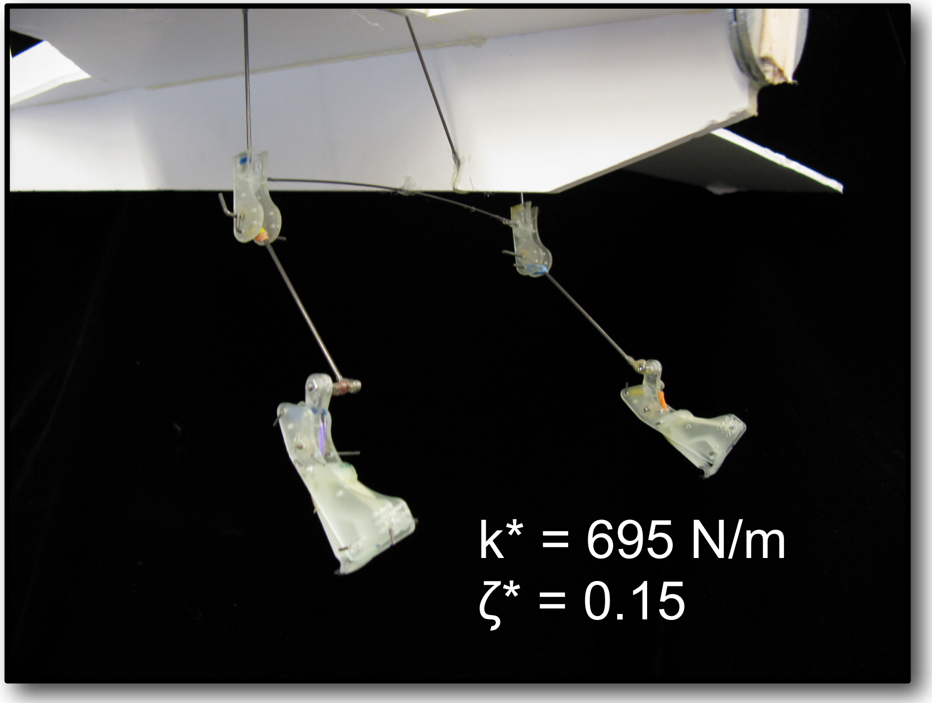
$$b = \frac{F_{max} - kx(t)}{v(t)}$$

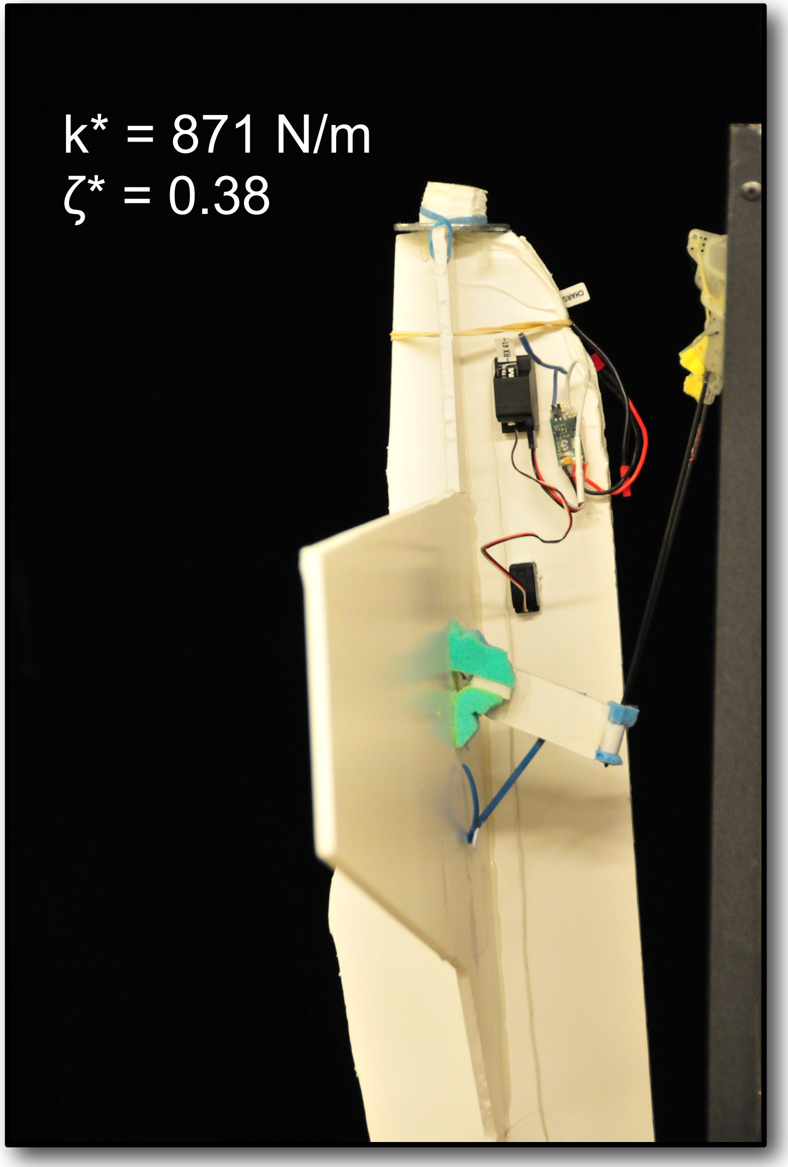
- Urethane foam exhibits reduced damping at high velocity



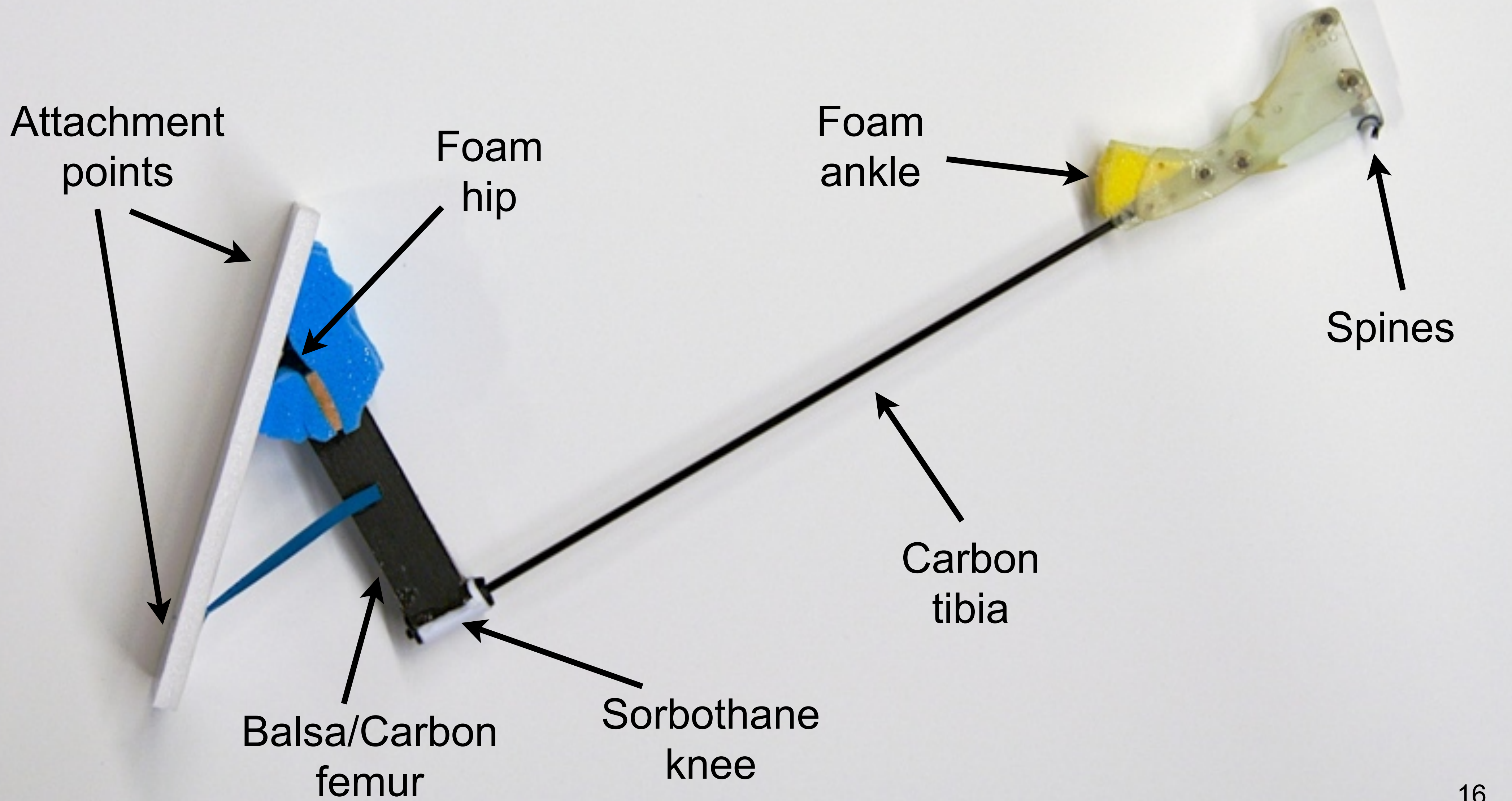
Suspension Designs





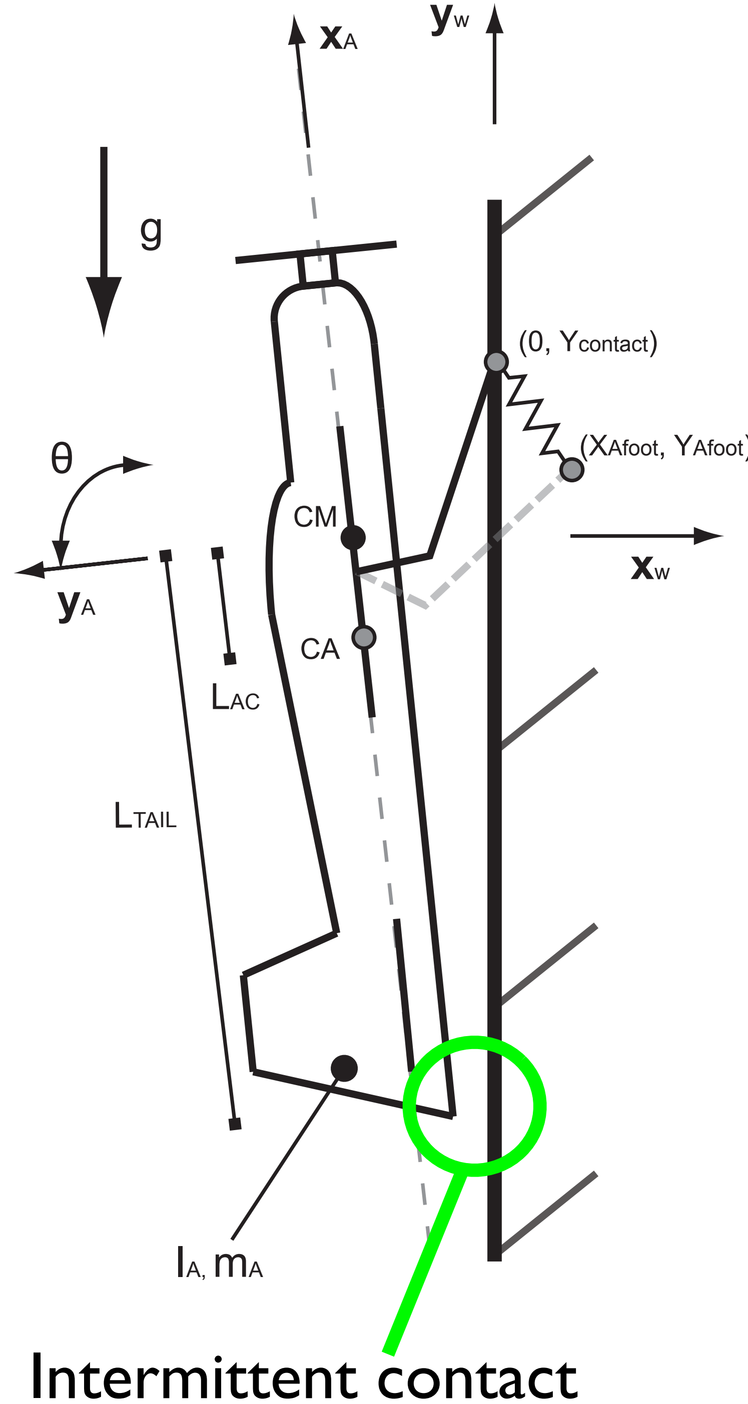


Leg Structure



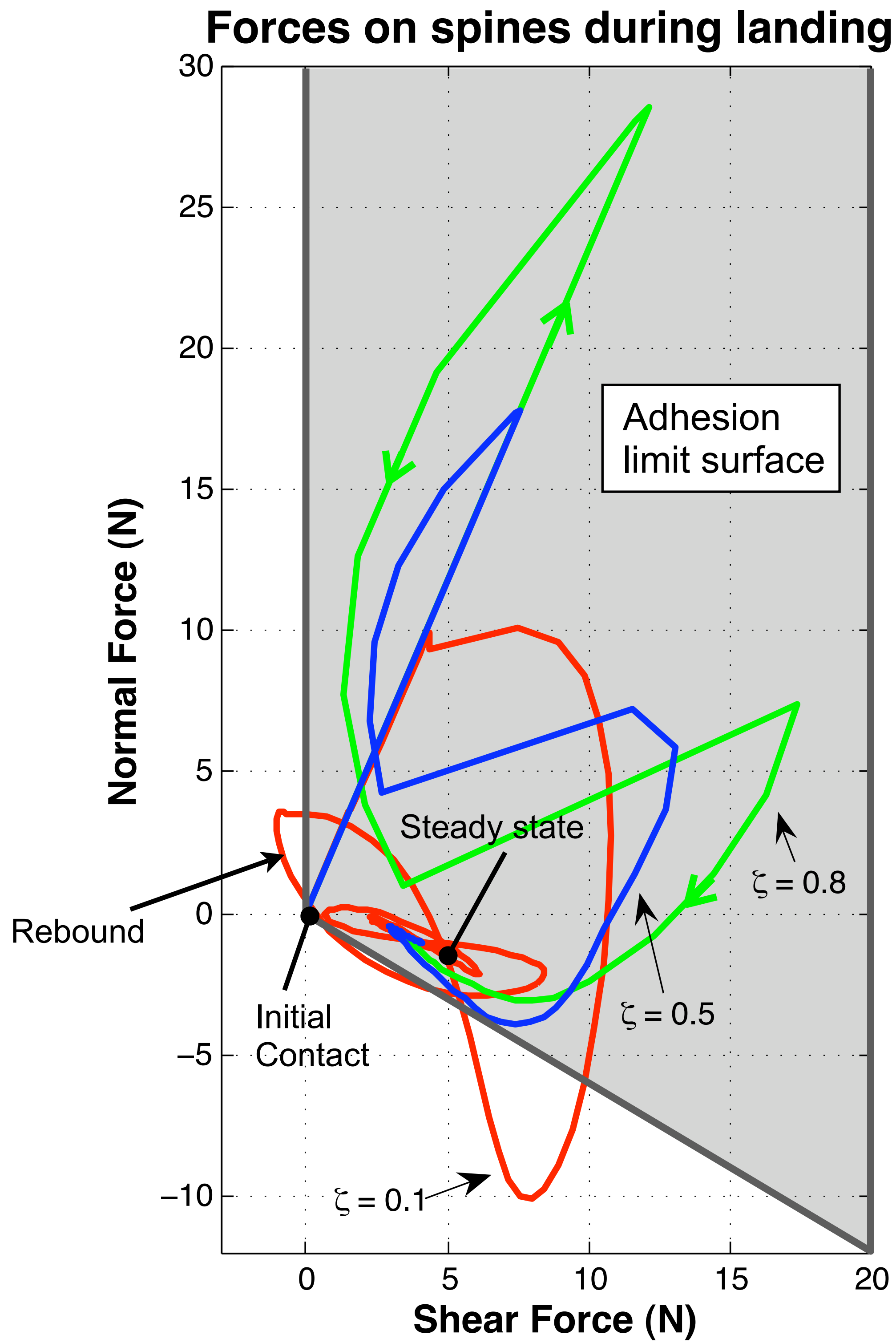
Planar Model

- Simple cartesian suspension model for now...
- Wing and control surfaces modeled as flat plates [Cory & Tedrake 2008]
- Equations of motion generated using Kane's Dynamics
- Used to study the effect of:
    - Incoming velocities
    - Suspension parameters (foot location, linkage non-linearity, etc.)
    - Improve landing forces on the spines



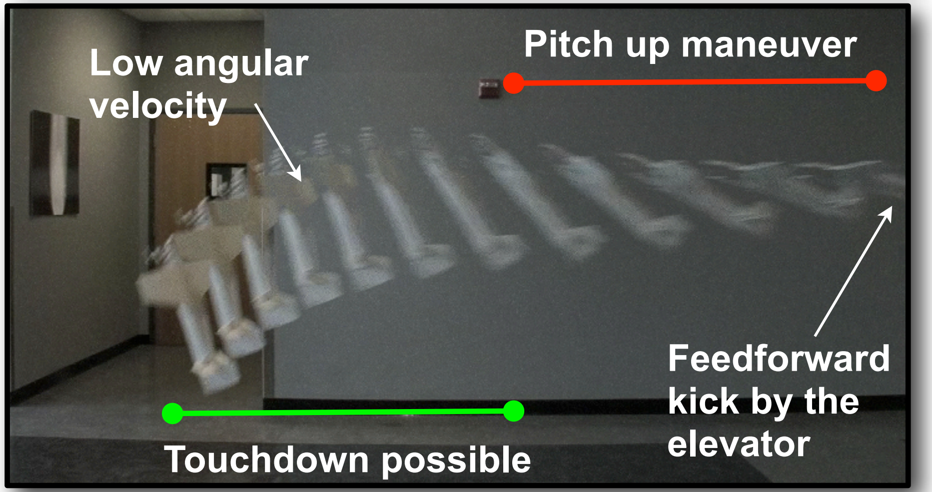
Planar Landing Simulation

- Loading trajectory is important
- Low damping ratio:
  - Ratio Fn/Fs too high
  - Rebound
- High damping ratio:
  - High peak force
- Moderate damping:
  - Ratio Fn/Fs within adhesion limit surface



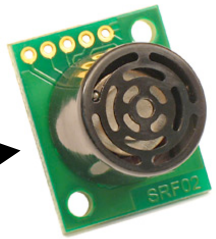
Trajectory/Control

- Previous research focuses on low contact velocity:
  - Low controllability at low velocity
  - The longer the approach, the riskier it gets (gust, etc)
- Spines need normal force to engage, **we want forward velocity**!
- Use the dynamics of the plane to reach the successful perching envelop of the suspension

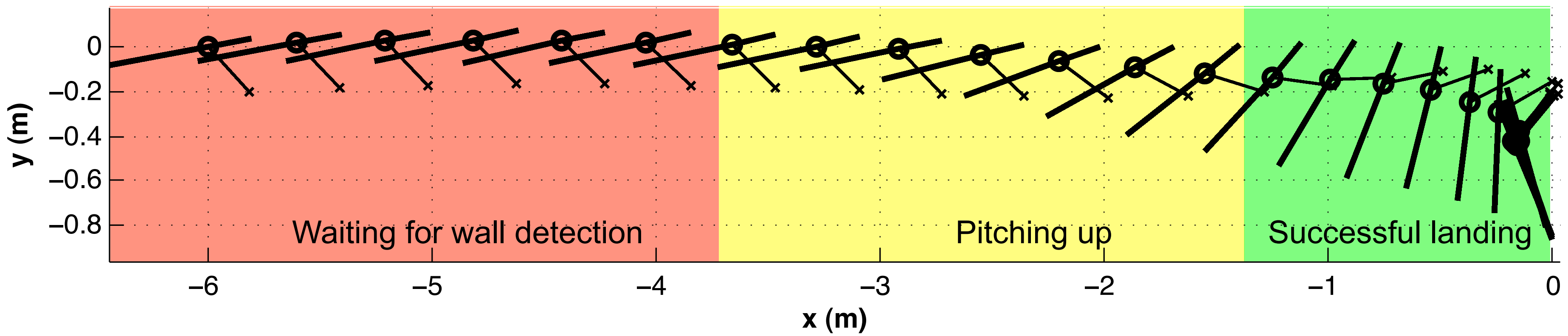


Perching Strategy

1. Fly toward the wall at about 9 m/s
2. Detect the wall with ultrasonic sensor
   - 20 Hz, 6 m range
3. Pitch up to slow down for landing (take about 2-3m)
4. Touchdown possible for about 1.5 to 2 m before impact
5. Touchdown at about 2 m/s, let the suspension absorb the impact



Simulated trajectory of the perching maneuver

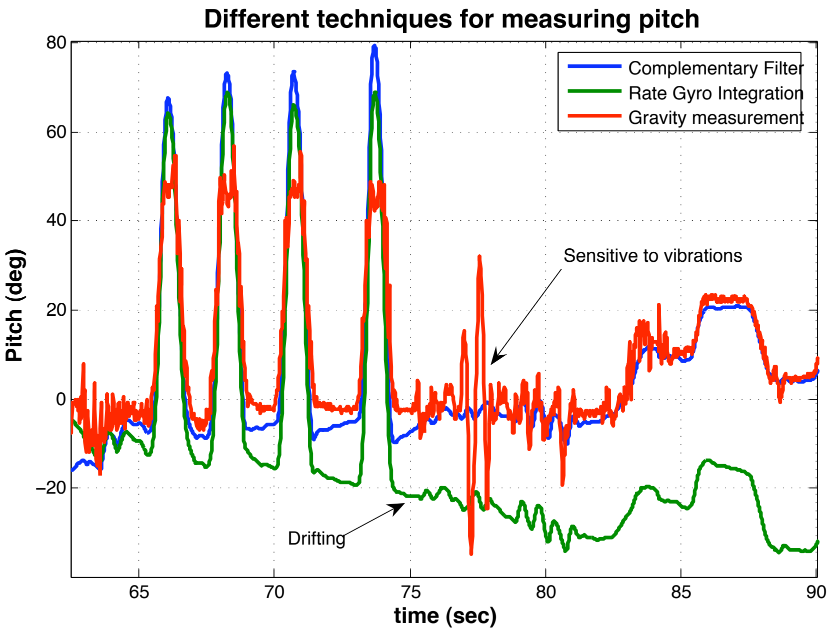


Onboard Sensors

- Simple wall detection using the LV-Maxsonar:
  - Range of 6 m
  - Update rate of 20 Hz
- Onboard accelerometer and gyro are used for data analysis
- Combined using a second order complementary filter:

$$\left(\frac{\tau s+1}{\tau s+1}\right)^2 \theta(s) = \frac{\tau^2 s}{(\tau s+1)^2}\dot{\theta}(s) + \frac{2\tau s+1}{(\tau s+1)^2}\theta(s)$$

- Need something better!!!



Perching

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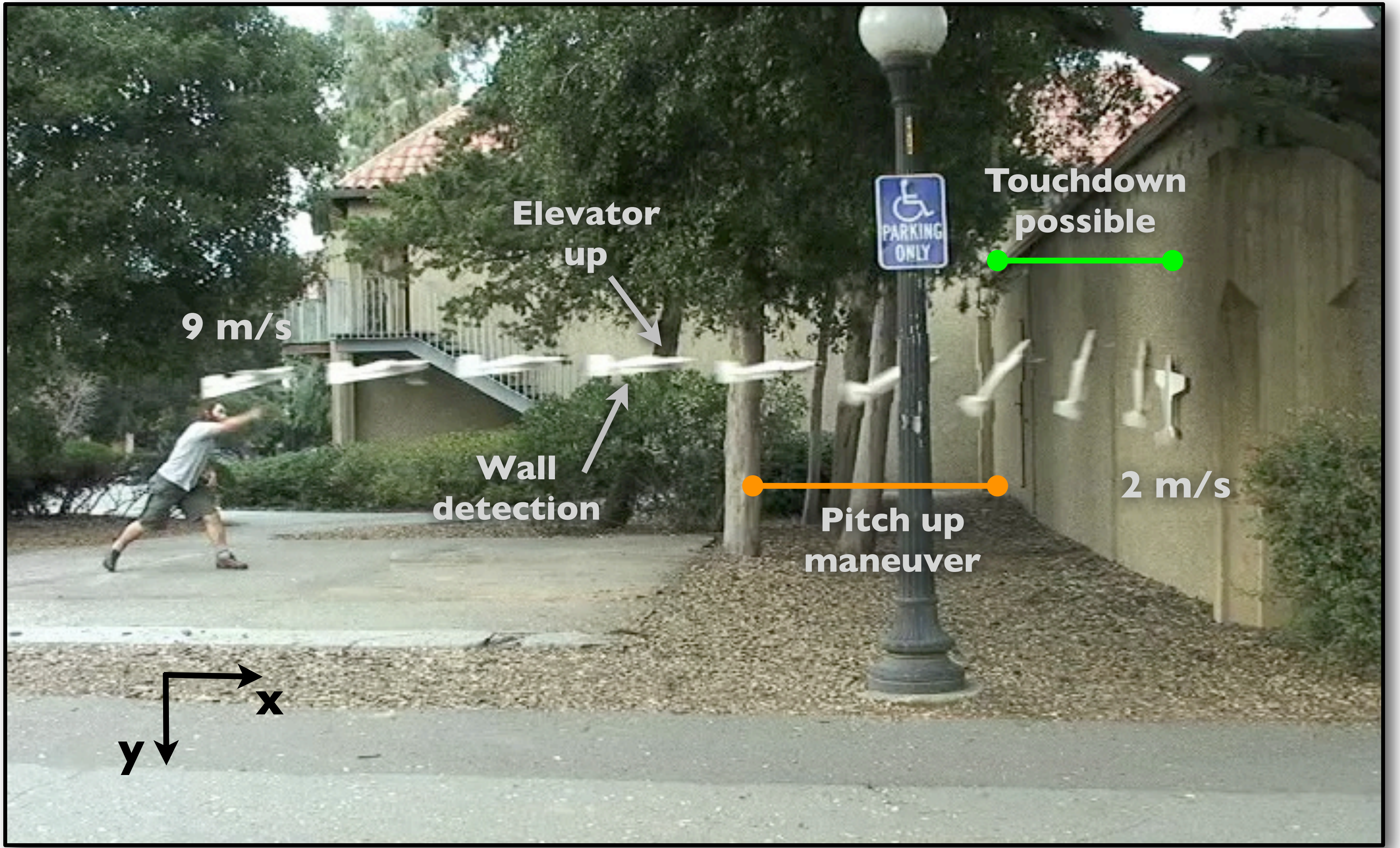
June 10th, 2009

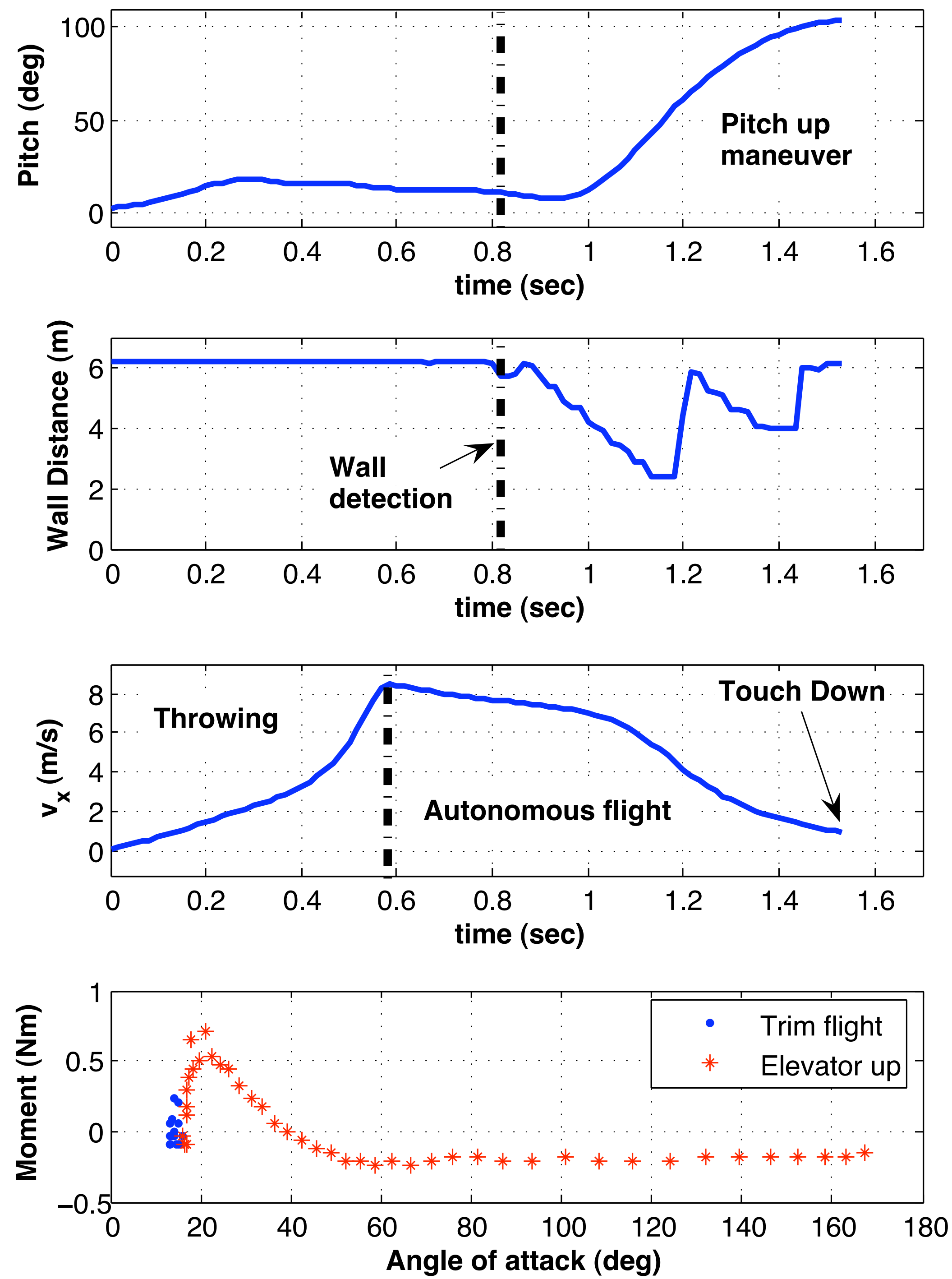


30 successful landings (10 autonomous, 20 in manual control)... out of 40!

- Pitch = 60 to 105 deg
- Pitch rate = 0 to 200 deg/s
- v_x = up to 3 m/s
- v_y = up to 2.7 m/s (downward)

Landing Data

- Wall detection at 6m
- Maneuver duration of less than 0.7 sec
- Ready to perch starting at t = 1.3 sec
- Lands at 1 m/s
- Most of the elevator action happens at low angle of attack



Improvement and future work

- Land on more challenging surfaces
- Trajectory optimization
  - Maximize horizontal distance travelled while ready to perch
  - Add propulsion
- Real conditions landing (windy, side approach, etc.)
- Take off from the wall!!

Conclusion

- A properly tuned mechanical system simplifies the perching maneuver
- Suspension is essential for:
  - Proper spine engagement
  - Maintaining controllability
  - Reducing control & sensor requirements
- Only 7% (28g) of total airplane mass
- Perching is interesting for a wide range of applications
- **Perching is pretty cool!**

Questions?

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